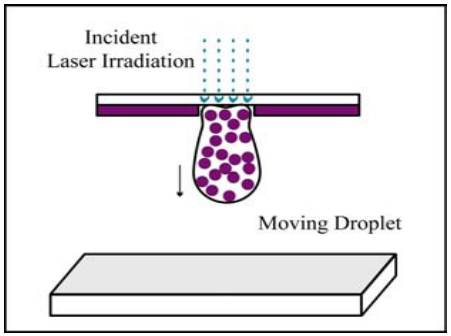
"On-the-fly" Materials Modification During Laser Direct-Write Deposition of Micropower Sources

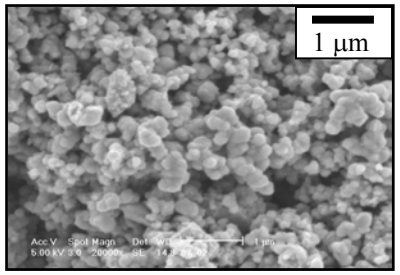
Craig B. Arnold, Princeton University, DMR-0346497

A recognized need for miniaturized power sources (~1-10 mm^2) exists in national security applications, but the techniques currently available to produce such small power sources require secondary processing such as high temperatures or pressures that can be detrimental to the sensitive materials used in many microdevices. In this study we examine the fundamental materials response of these electrochemically active systems to laser irradiation *during* deposition, in order to understand and control the properties of these substances and limit the need for secondary processing. Incident laser irradiation appears to structurally modify the hydrous ruthenium oxide ultracapacitor material as shown by localized regions of melting and densification. Electrochemical modifications are also observed with a particular benefit of improved high rate behavior.

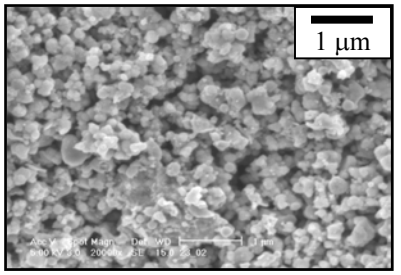


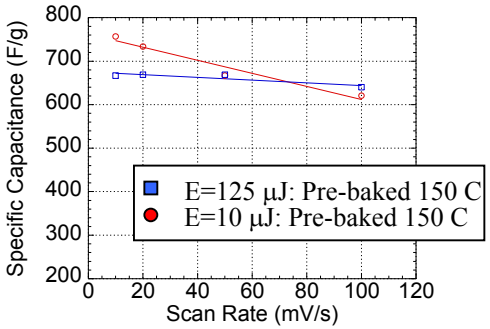
Laser forward transfer technique for direct-write deposition and modification of electrochemically active materials

Low laser energy



High laser energy





Specific capacitance versus scan rate for low and high laser energy

This nugget represents the work performed under DMR-0346497 which began on Sept. 15, 2003. The main objective of this study is to understand the fundamental laser interactions with the materials during deposition by laser forward transfer. A better understanding of the mechanisms will not only enable control over the properties of the deposited materials, but also enable one to modify the materials "on-the-fly" thereby avoiding deleterious processing steps on sensitive substrates.

Over the past year, we have performed extensive studies of the effects of the initial laser on the deposited materials. Contrary to previously published work on laser forward transfer, the energy of the incident laser plays an important role in determining the properties of the deposited materials. Electron microscopy reveals localized melting and densification when the hydrous ruthenium oxide material is exposed to increasing laser energies. The basic model for laser interaction is that the energy is locally absorbed at the interface between the glass plate and the ink. Based on our results, we believe this model still holds, however, the observed changes in the material structure are due to thermal effects of the dissipation of the absorbed energy during flight.

The electrochemical effects of these structural changes are observed in the CV studies of the deposited materials. Although in many cases, the higher laser causes a decrease in the actual capacity of the material, the capacity at high scan rates appears to be improved by the laser interactions. In keeping with a model of protonic conduction along disordered regions of the hydrous material, we believe the improvement at high rates is due to the increased disorder introduced in the melted/resolidified regions of the electrode material.

Finally, the sensitivity to laser energy (i.e. capacitance vs laser energy) depends on the method in which the hydrous ruthenium oxide is prepared. The response varies from a sharply negative (decrease in capacity with increase laser energy) to slightly positive. The most sensitive material appears to be that which was "optimally" preprocessed according to methods in the literature.

This work is currently being written up for journal publication and should be submitted within the next few months. In addition, we presented a poster at the Gordon research conference on laser interactions with materials earlier this summer.

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Education:

• A variety of undergraduates from different academic departments have contributed to this project. During the fall of '03 we had one undergraduate student. Currently, one undergraduate physics major (Adam Hopkins) is being advised for his senior thesis and another undergraduate student (Dan Recht) is working on his junior research project on this project.

• A new graduate student (Guodan Wei) has joined the project this fall

• This program employed two REU students this past summer (Ted Yeh (Princeton), Joshua McNeur (U. Chicago))

• Student contributions to this work was presented at the Gordon Research Conference on Laser Interactions with Materials this past summer. Additional work from the current students is scheduled to be presented at the Photonics West conference in January 2005.

•The PI has become the faculty advisor for Princeton University undergraduate materials research club

Outreach:

• The PI has served as associate chair of the Materials Research Society (MRS) academic affairs committee, since September 2003.

• Presented demos in middle-school Science and Engineering Expo held at Princeton in March.

• Participated in MRS Strange Matter Exhibit at Liberty Science Center, Jersey City, NJ

PI presenting polymer demo to youngsters at the MRS Strange Matter exhibit at the Liberty Science Center, Jersey City, NJ April 25, 2004

Outreach:

1) MRS Academic Affairs Committee: The PI has been serving as the associate chair of this committee since September 2003. During this time, the main activities include developing a web site devoted to Materials Science Curriculum issues, restoring the Undergraduate Materials Research Initiative (UMRI) program to the society, and strengthening the ties between MRS university chapters and the national organization.
2) Participated in middle-school Science and Engineering Expo held at Princeton on March 17, 2003. Presented demos on polymer materials, processing of materials, and electrochemical materials related to batteries and capacitors. Interviewed and quoted in article for Trenton Times newspaper, March 18, 2003.
3) Participated in Strange Matter exhibit at Liberty Science Museum, Jersey City, NJ, presenting to elementary school students and parents about polymers, batteries, mechanical properties of materials. http://www.princeton.edu/pr/home/04/0421_liberty/hmcap.html.